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Regarding

Carbon Sequestration: Risks, Opportunities, and Protection of Drinking Water

Submitted to

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Committee on Energy and Commerce

Subcommittee on Environment and Hazardous Materials

My name is Ian Duncan. I have a PhD in Geological Sciences and I am an Associate Director of the Bureau of Economic Geology (BEG) at the University of Texas at Austin. The University of Texas has arguably the largest group of researchers in the country focused on CO2 sequestration in deep brine reservoirs. The BEG is engaged in research in a broad range of energy related and environmental issues including CO2 sequestration. The BEG's Gulf Coast Carbon Center (GCCC) is an industry-academic-NGO collaboration working on geologic CO2 sequestration including Enhanced Oil Recovery CO2 EOR.

The GCCC's Frio Pilot Injection Project, led by the BEG's Dr Susan Hovorka and funded by the DOE's National Energy Technology Laboratory, was the first highly instrumented CO2 injection experiments in the world. The Frio Brine Pilot Injection project (conducted 2004 to 2007) was:

- A first-of-a-kind field investigations into the viability injecting CO_2 into a brine-filled sandstone reservoir for long term geologic storage or sequestration; and
- A carefully monitored, small-volume (1,600 tons), short-duration experiments using injection of CO_2 into high-permeability brine-bearing sandstone to test the effectiveness of computer modeling and various monitoring techniques.

The Frio Brine Pilot project was designed to begin to develop the understanding necessary to begun large scale CO_2 injection. No evidence has been found of CO_2 leaking or behaving in any way not predicted by pre-injection computer simulations. Extensive monitoring has not detected any evidence of leakage of the geologic reservoir. The Frio Pilot Injection has shown that relatively low-cost, off-the-shelf, monitoring techniques can provide cost effective monitoring of CO_2 injections for sequestration. This project has also confirmed the utility of computer simulations to accurately model the fate of CO_2 injected into subsurface brine reservoirs.

The GCCC currently has a significant field-test of CO2 sequestration in brine reservoirs underway in Mississippi (Denbury resources Cranfield CO2-EOR site). This field test seeks to show the effectiveness of CO2 sequestration, and how we can best predict and document the long term retention of CO2 through modeling and monitoring. These studies are funded by about $50 million in Department of Energy funds (over 10 years).

For the past nearly four years I have been doing research on the role that CO2 sequestration in deep brine reservoirs and associated with CO2 enhanced oil recovery (CO2-EOR) can play in mitigating greenhouse gases in the atmosphere and in increasing domestic oil production in the US. Recently I have been working on developing a regulatory framework for CO2 sequestration in brine based on performance standards rather than prescriptive standards (command and control).

The key points that I would like to make are:

(1) Based on all the available information I believe that large scale CO2 sequestration in deep brine reservoirs can be done safely and effectively without endangering the nation's underground sources of drinking water (USDW).

(2) Based on my review of the recent EPA draft regulatory documents, I commend the EPA for its quality and comprehensiveness. I compliment the EPA staff on their efforts to foster broad stakeholder input into their process.

(3) I will not be making specific comments on the details of the EPA draft as I do not want to preempt the mechanism for stakeholder comment that the EPA has in place.

(4) I have a concern that the EPA does not have any legislative mandate to require, encourage or even suggest that operators choose the most optimal (lowest risk of leakage) sites available.

(5) It is critical that EPA be given sufficient resources (including trained professional staff engineers and scientists) to fully develop, implement, and enforce regulations for carbon sequestration.

(6) Performance standard based approaches to regulating CO2 sequestration offer considerable advantages over prescriptive approaches.

(7) In the near term, CO2-EOR combined with appropriate monitoring, mitigation, and verification, (MMV) can make a significant contribution to mitigating increases in CO2 emissions by putting man-made CO2 (CO2-A) into permanent storage in depleted oil reservoirs.

(8) Congress should appropriate funds for the DOE to support university research into CO2 sequestration associated with CO2 EOR and for individual investigator research outside of the Sequestration Partnership program. Such funding would help produce young engineers and geologists trained in CO2 related technologies and alleviate a shortage that is critical now and will grow more so in the near future.

DEVELOPING A SEQUESTRATION CAPABILITY IN THE US

CO2 sequestration will involve the capture of anthropogenic CO2 (typically from electric power plants) followed by deep subsurface injection into oil and gas reservoirs, deep unmineable coal beds or deep brine reservoirs. Approximately 80% of the CO2 injection in the world today takes place in the Permian Basin of Texas and New Mexico, making the region the largest commercial market for CO_2. Texas corporations and technical workers have a unique experience base and outstanding safety record, in pipeline transport and subsurface injection of CO_2. Since the early 1970s, CO_2 has been injected into many Permian Basin oil reservoirs to enhance production. Injected CO_2 is dominantly produced from natural accumulations and pipelined to the Permian Basin. In addition, on the order of ~10% is now derived from other sources such as gas processing plants where the CO_2 would otherwise have been released to the atmosphere. Currently roughly 30 million metric tons (MMt) of CO_2 are injected annually in the Permian Basin in operations that are closed-cycle. In other words, CO_2 that is produced from the oil reservoirs in association with the recovered oil is recycled (re-injected into the reservoir for additional recovery).

Many individual injection operations in the Permian Basin are at the scale of CO_2 production associated with coal burning power plants. CO_2-flooding for enhanced oil recovery (EOR) has been active at SACROC Oil Field in Scurry County since 1972. Kinder Morgan the current operator at SACROC currently injects ~13.5 MMt CO_2/yr and withdraws/recycles ~7 MMt CO_2/yr, for a net storage of ~6.5 MMt CO_2/yr. For comparison, a 500 MW pulverized coal power plant produces roughly 3–4 MMt CO_2/yr. This magnitude of annual CO2 storage at SACROC is over six times the rate of Statoil's Sleipner project offshore Norway.

The Gulf Coast has a large potential for CO_2 EOR outside of the traditional area of CO_2 EOR in the Permian Basin. Using miscibility screening criteria, BEG staff have inventoried 767 oil reservoirs where miscible CO_2 EOR could be applied for an additional 3.8 billion barrels of oil recovery. By way of comparison, annual oil production in USA is about 1.86 billion barrels. This incremental production target is attractive in terms of wellhead value, tax revenue, and economic activity. This EOR activity would lead to the use of large amounts of CO_2, however, it is small in the context of the projected 55 to 70 billion tons of CO_2 emissions for the Gulf Coast over the next 50 years. Deep brine reservoirs in the Gulf Coast have been estimated by BEG staff to have a sequestration capacity about 4 times this value (that is over 200 billion tons of CO2).

EOR results in storage of CO_2 dissolved in residual oil, dissolved in brine, and trapped as an immobile supercritical phase. Experience in mature Permian basin CO2-EOR projects is that 30 to over 60% of the injected CO_2 is retained in the reservoir over a year of injection (starting at 100% retention for the initial phase of the project). Due to recycling (capture and reinjection of CO2 produced with the oil), it is likely that appropriate MMV techniques would demonstrate that in most instances 99% +/- .05% of the CO2 used is ultimately sequestered in the oil field. However, the volume retained as a by-product of EOR is small relative to total point source emissions. The large synergy between EOR and reducing carbon emissions is that EOR would enable the construction of an infrastructure linking sources to reservoirs. Very large volumes of brine reservoirs can then be accessed beneath oil production, a concept that we describe as stacked storage. Existence of an infrastructure would reduce the cost of storage of Gulf Coast power plant, refinery, and chemical plant emissions for the next 50 years or more.

The Gulf Coast of the USA is a region of high CO_2 emissions that overlie thick, extensive, and well known subsurface geologic formations. The path forward toward developing an economically viable system for capture and storage includes: (1) development of a climate favoring construction of gasifiers using coal, lignite, petcoke and/or biomass as sources (IGCC electric power plants for example), (2) construction of a pipeline backbone to transport CO_2 regionally, (3) a market for CO_2 for EOR in areas beyond the traditional area of use in the Permian Basin, and (4) development of stacked storage, using deeper brine-bearing formations beneath hydrocarbon reservoirs.

Sequestration credits may play a significant role in future CO2 EOR based on anthropogenic CO2. The criteria to qualify projects for CO2 credits are likely to evolve as the industry matures. A recent Texas law creating a tax credit for CO2 EOR using anthropogenic CO2 requires projects to establish a reasonable expectation that they can meet a performance standard of 99% retention for 1,000 years. To meet this standard, operators will likely have to: characterize the seal for their reservoir and demonstrate that it is compatible with this standard; design and implement an appropriate monitoring program and complete a CO2 life cycle analysis to verify the amount of CO2 avoided.

Up until now, CO2 purchase has been the largest cost component of a CO2-EOR flood. As a result engineers and geologists in companies and the Universities have developed and refined technologies and approaches to minimize CO2 usage in CO2-EOR projects. We may be entering a new regime in which CO2 injection gains credits that will change the fundamental economics. Under these circumstances new or previously little-used approaches to CO2 EOR projects such as vertical floods and CO2 alternating with CO2 foam may become viable. Such approaches offer great opportunities for increasing the total oil recovery and maximizing CO2 storage. However research in combination with full scale field test will almost certainly be necessary to convince companies of the viability of these and other “game changing” technologies.

Although this testimony has focused on the Gulf Coast and Permian Basin of Texas, significant CO2-EOR potential also exists in a number of other states including Louisiana, New Mexico, Oklahoma, Wyoming, Illinois, Michigan, California, Kansas, Mississippi, North Dakota, Montana and others. In the context of economic growth, global oil demand and atmospheric mitigation of CO2, a ‘first step’ mechanism is required to sequester large volumes of CO2 in EOR operations in a manner that later allows pure CO2 storage to initially ‘piggyback’ via the commercial leverage of the oil recovered.

CO2-EOR can create an effective bridge to CO2 sequestration in brines, by providing the financial capacity and rationale for developing a CO2 capture, compression and transportation infrastructure across a significant portion of the US that can later be used for large scale CO2 sequestration in deep brine reservoirs. To facilitate this happening, Congress should provide a policy/regulatory environment that encourages CO2-EOR operators to change business as usual by: a) utilizing CO2-A when available at reasonable cost from capture at power plants; b) creating and implementing MMV plans to provide assurance of permanent sequestration; and c) conduct life cycle analyses of their projects to measure CO2 avoided.

CREATING A NEW REGULATORY FRAMEWORK FOR CO2 SEQUESTRATION

The two key aims of a regulatory framework for CO_2 injection should be: to ensure public health and safety; and to prevent environmental damage, particularly damage to drinking water resources. Additional issues that should be addressed by the regulatory process include:

- The concerns of local government and local residents. Any negative environmental consequences of geologic sequestration are likely to impact the local community
- Providing a mechanism for stakeholders and the general public to have effective input into the both the permitting process and the integrity of subsequent regulatory oversight.
- Supporting confidence of the market place for CO_2 sequestration credits by assuring transparency.
- Assuring adequacy of long term monitoring, mitigation and remediation efforts.

(A) Encouraging Optimal Site Selection through Creating a General Permitting Process for Sequestration

An aim should be to require the selection of sites that have low risk of leakage. The Carbon Capture Project, an industry based research collaboration, has suggested that the first key to lowering the risks associated with CO_2 sequestration projects is "careful site selection". The long term risk of leakage of brine sequestration projects is very much dependant on site selection. Permitting is by its very nature a binary (yes or no) decision. Currently the EPA has no legislative mandate to encourage selection of the best sequestration targets.

One approach to encouraging companies to select the sites that are least likely to leak based on best available scientific knowledge is to implement the General Permit model of Nicot and Duncan 2008. In this paper we suggest that States, with guidance from Federal agencies (U.S. Geological Survey, U.S. EPA), should be responsible for developing regional evaluations of geology and engineering properties of potential brine reservoirs for CO_2 sequestration. Such studies could include regional static reservoir models, numerical models of the evolution of CO_2 plumes, and regional risk assessments. State and Federal governments should be proactive in starting regional studies with stakeholder (general public, local governments, operators, CO_2 generators) input that would rank areas according to criteria developed from such broad input. Rankings based on a systematic approach to risk assessment could be established with the help of decision-support tools specifically developed for this purpose. These "risked-based" or "risk-informed" approaches have already been used for other performance-based permitting systems developed by the U.S. EPA. The EPA has a long history of ranking sites with some degree of success. The DRASTIC program and Risk Based Corrective Action are two examples. Similar schemes could be used for carbon-storage sites.

As the permitting system evolves, it will be important to build in market-based incentives to encourage innovation and to reward sound stewardship. Such incentives could include streamlined permitting, extension of existing permits to encompass multiple injection projects into the same brine reservoir, and waiving of some requirements on the basis of an exemplary track record. Innovative permitting can lower overall cost of sequestration, at the same time encouraging technical innovation and improved performance.

A hierarchical approach to permitting could be developed. The first level, the general permit phase, would be based on regional assessments of specific brine reservoirs. A State agency responsible for the permitting process of geologic sequestration carries out regional-scale assessments for suitable target regions on the basis of sophisticated modeling and extended data sets. A national agency, such as U.S. EPA, could also be involved when UIC oversight responsibility has not been delegated to the State. National/Federal agencies could also help in or be required to providing consistency across lower-level entities (states, provinces, etc). Counties, metropolitan areas, and subregional agencies could carry out a subregional-scale assessment. The results will then be used by the designated State or Federal agency to create general permits for specific regions for individual and/or groups of brine reservoirs. Individual operators apply for permits (as in the case of deep injection wells).

For early-entry projects it likely will not be possible to implement the hierarchical approach without unnecessarily delaying initiation of geologic sequestration. For large scale implementation of sequestration EPA should be given a legislative mandate that enables it to regulate sequestration in a regional context rather than on a well by well or even project by project basis.

(B) Performance Standard Based Approaches to Regulation

To have a significant impact on decreasing the rate of increase of atmospheric CO2 levels, geologic sequestration in deep brine reservoirs will have to occur on a very large scale. The scale of individual injection projects is likely to be as large as or larger than any previously permitted under the UIC program. In addition CO2 is more buoyant (though less hazardous) than other fluids regulated by the UIC process. Performance standard based approaches are the best able to adapt to evolving understanding of the technologies involved. Additionally, a performance-based framework will increase the quantity and quality of information available to the public and other stakeholders.

The regulatory landscape can be viewed as a continuum between prescriptive and performance- based regulation. Prescriptive regulation is based on prescribed actions. In contrast, performance-based regulation sets goals for outcomes. The specific means to achieve the outcome is left up to the regulated entities. Perhaps inevitably particular regulatory frameworks have become associated with particular political parties or even philosophical movements within political parties.

New Zealand's Building Act of 1991 was the first to fully implement a performance-based regulatory regime across a whole industrial sector. This legislation represented a specific philosophy based on faith in market forces and minimal governmental interference to maximize efficiency. Part of these reforms allowed private certifiers to monitor compliance with desired performance goals. Unfortunately within a decade New Zealand newspapers were investigating what became known as the ''leaky building crisis'', caused by a pervasive failure of the regulatory approach. Over 18,000 houses were affected; many were determined to be uninhabitable.

The record of an official inquiry in 2002 into the crisis identified a number of problems including imprecise specification of performance standards as well as systemic deficiencies in accountability and enforcement. New Zealand's response to the leaky building crisis was the 2004 Building Act which created: increased accountability;

introduced tighter specification of performance standards; stronger monitoring of inspection practices; and increased rigor for licensing of certifiers.

Based on review of the New Zealand experience the following recommendations can be made to strengthen performance standard based approaches to regulating CO2 Sequestration:

Create performance standards that are as clear and specific as possible

Justice Breyer has noted that often performance standards are hard to enforce due to the difficulty of developing appropriate tests for adequacy of performance. Performance standards should be expressed in a quantitative form wherever possible. Clearly performance metrics that are expressed in well calibrated shades of grey (probabilistic) are to be preferred over binary black/white (or yes/no) measures.

Create hybrid regulatory frameworks that combine traditional specification based approaches (where this makes sense) with performance based approaches.

Some situations call for a "hybrid approach" that combines performance standards with prescriptive regulations. One approach is to add provisions for alternative compliance mechanisms. Such provisions can enables allow firms to 'opt-out' of prescriptive standards if they can get a comparable level of performance in other ways.

Develop clear and effective reporting requirements

If the required effort to implement the standards is unclear then this can increase the cost of compliance compared to prescriptive regulations. Where possible, for each permitted project, specific metrics should be developed for each performance standard. These metrics, once agreed on should become part of the permit.

Create strong professional accountability of regulatory staff and third party certifiers.

As was found in the "leaky buildings crisis" in New Zealand, performance based regulatory frameworks function as intended only if there is effective enforcement. Strong codes of practice for regulatory professionals and third party certifiers that encourage exercise of sound professional judgment should be required by Congress.

Maximize transparency by increasing information available to the public

Regulation determines levels of environmental quality through public processes. Increasing the amount and quality of information available to the public will improve the transparency of the regulatory process. Non-Government Organizations (NGOs) can play a very useful role in acting as surrogates for the local community in monitoring projects.

Create an environment that encourages proactive compliance by regulated entities

Incentives to reward sound stewardship could include "fast track" permitting; extension of permits to multiple injection projects in the same brine reservoir; and waiving of some requirements on the basis of an exemplary track record.

Develop accountability through performance audits

Strategies should include: (1) self audits by regulated entities themselves particularly when the self reporting is done by well trained, certified professionals; (2)

independent audits by third party, certified professionals; (3) audits by a regulatory agency; and (4) review of audit results by independent oversight boards composed of experts in the field.

Build in "learn-as-you-go" into the regulatory framework as an ongoing adaptive approach to process improvement by systematically both tracking learning on multiple levels and achieving consensus on the key lessons learned.

The Carbon Capture Leadership Forum has suggested that a 'learn-as-you-go' strategy will be essential to implement sequestration in a timely manner. The ultimate expression of "learn-as-you-go" is a regulatory framework that accommodates adaptive evolution of the permitting process itself.

Proactively integrate computer modeling into the regulatory process to maintain both flexibility and accountability

The results of computer simulations will likely play a key role in both preparing and evaluating permit applications for large scale CO2 injection projects.

(C) Can Performance Standards be developed for Regulating CO2 Sequestration in Deep Brine Reservoirs?

Performance standards are objectives that the regulatory agency (representing the interests of society in general) place on regulated entities.

The FutureGen Alliance's Request for Proposals (RFP) for injection sites established a prescriptive standard for seals. The Alliance had specific requirements for an acceptable primary seal, stating that the seal "must have sufficient thickness (greater than 20 feet [6 meters])". Requiring a minimum thickness for a seal is an arbitrary prescription. A useful performance standard for an adequate seal is:

Performance standard 1. The operator must demonstrate that the reservoir has a top seal and other elements of a natural and engineered containment system with petrophysical and geological properties consistent with protection of underground sources of drinking water (USDW) from contamination from injected CO2, pollutants mobilized by the CO2 injection, and/or water high in total dissolved solids (TDS) set in motion by pressures induced by the injection.

Such a standard could be supported by more technical sub-standards such as:

Performance Standard 1a. An acceptable seal must have either a measured capillary entry pressure higher than the predicted maximum pressure at the base of the seal or a combination of permeability and thickness such that the seal effects a sufficient barrier to the flow of CO2 under the conditions of the specific project such that the retention performance standard is assured. It is acceptable to document the effectiveness of the seal by analogy with the equivalent sealing unit elsewhere retaining natural gas or oil, assuming that enough information is known about each seal to consider them equivalent (in their permeability and capillary entry properties).

Whether or not performance standard based regulations are integrated into the EPA's approach to regulating CO_2 sequestration, I believe that the EPA will need significant additions to their professional staff to enable effective regulation. Regulating CO_2 sequestration will involve a wide range of scientific and engineering issues such as: geochemical interaction of rock, gas and brine; the geomechanical effects of high injection pressures; and evaluation of computer simulations of multi-phase flow. All of these issues require well trained professionals to evaluate. Congress should make sure that the EPA has sufficient staff and resources to develop and enforce their regulatory framework for CO_2 sequestration.

EVALUATING THE RISKS ASSOCIATED WITH GEOLOGICAL CO2 SEQUESTRATION

Based on the available information from over 35 years of CO_2 injection into geologic reservoirs in the Permian basin of Texas and on scientific knowledge from natural CO_2 reservoirs, I believe that large scale CO_2 sequestration can be done safely and effectively without endangering the nation's underground sources of drinking water (USDW). Although safety and health issues are always of paramount concern, the excellent safety and health record of the CO_2 industry in the Permian Basin of West Texas, and the absence of known negative impact on USDW suggest that these issues are not a major component of the business risk faced by a putative carbon sequestration industry. Having said this, it is very unfortunate that very little research funding is available to study and assess the wealth of potential information available from studying the results of the long term CO_2 injections in the Permian Basin by CO_2 EOR operators.

Apart from a small DOE funded research project through the Southwest carbon Sequestration Partnership and led by the BEG, only very limited research is being done in this crucial area. I recommend that Congress should appropriate funds for the DOE to support university research into CO_2 sequestration associated with CO_2 EOR particularly in the Permian basin which has the longest history of CO_2 injection in the world. An aggressive research program including pilot projects would help improve the performance of current EOR activity and enable the development of new more effective approaches that could increase oil recovery, reduce the geological and technical risks, and enhance sequestration rates incidental to CO_2-EOR. Such funding would also help produce young engineers and geologists trained in CO_2 related technologies and alleviate a shortage that is critical now and will grow more so in the near future.

It has recently been suggested that an effective system of regulation for geologic sequestration should share the long-term risks of sequestration between the public and private entities. I prefer to place the emphasis not on the government sharing the long term risk but rather on reducing risk of leakage by creating a regulatory framework that: (1) provides a mechanism to assure optimal site selection (2) minimizes risk by requiring adequate site characterization; (3) assures early detection of any leakage by insisting on deep monitoring; and (4) requires preventive action to lower the chance of leakage leading to adverse outcomes. Government resources should be deployed early in the project life cycle, focused on optimizing selection and evaluation of sites. Providing careful oversight of risk assessments and then requiring early and vigorous implementation of preventative action will be more valuable than reserving resources to remediate problems that could have been prevented.

In conclusion I am confident that we have the technical understanding, the scientific knowledge and the experience to implement CO_2 sequestration on a large scale in such a way that the nation's drinking water resources are effectively protected.